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Published in:
I E E E Photonics Technology Letters

Link to article, DOI:
10.1109/LPT.2011.2165702

Publication date:
2011

Document Version
Peer reviewed version

Widely Tunable High Power Tapered Diode Laser at 1060 nm

Ole Bjarlin Jensen, Bernd Sumpf, Götz Erbert, *Member, IEEE*, and Paul Michael Petersen

***Abstract*— We report a large tuning range from 1018 nm to 1093 nm from a InGaAs single quantum well 1060 nm external cavity tapered diode laser. More than 2.5 W output power has been achieved. The tuning range is to our knowledge the widest obtained from a high power InGaAs single quantum well tapered laser operating around 1060 nm. The light emitted by the laser has a nearly diffraction limited beam quality and a narrow line width of less than 6 pm everywhere in the tuning range.**

***Index Terms*—Semiconductor lasers, quantum well lasers, tapered lasers, laser tuning.**

I. Introduction

High power narrow line width diode lasers in the 1060 nm spectral region are of interest for many applications including spectroscopy and frequency conversion to the green spectral range [1]. The tapered diode lasers are currently attracting an increasing amount of interest as they combine high output power with good beam quality [2].

High power near diffraction limited tapered diode lasers have been realized at many operating wavelengths with a main focus on the red to near infrared spectral range [3,4]. For many applications narrow line width operation is required and various techniques have been investigated to achieve this. Different external cavity approaches including the use of diffraction gratings [5] and Bragg gratings [6,7] have been investigated as well as injection seeding using a low power narrow line width seed laser [8].

Recently, DBR tapered diode lasers have shown high output power and narrow line width operation and the simplicity and robustness makes this approach very attractive [9,10]. For some applications, however, tuning of the output wavelength is required and injection seeding or external cavity techniques can be used. In the 1000-1100 nm wavelength range, tunable, near diffraction limited external cavity tapered diode lasers have been developed with high output power of 4 W [7] and also large tuning ranges of up to 65 nm have been obtained [11]. An injection seeded tapered diode laser with an output power of up to 7.4 W at 1083 nm has been demonstrated [8].

Manuscript received May 13, 2011. This project was supported by the EU-FP6 integrated project WWW.BRIGHTER.EU contract IST-2005-035266.

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Here, we present the operation of a tunable, near diffraction limited external cavity tapered diode laser with an output power of up to more than 2.5 W and a wide tuning range of 75 nm centered around 1060 nm. To our knowledge this is the widest tuning range for an external cavity tapered diode laser in this wavelength region. Narrow line width operation is obtained over the entire tuning range.

II. Experimental setup

The tapered amplifier used in the experiments has a total length of 4 mm divided between a 1 mm long index guided single-mode ridge waveguide section and a 3 mm long gain guided tapered amplifier section. The taper angle for the amplifier is 4º resulting in an output aperture width of 210 µm.

The tapered amplifier is grown by metal-organic vapor phase epitaxy (MOVPE). The active region of the amplifier consists of a single 7 nm thick $In_{0.25}Ga_{0.75}As$ quantum well (SQW). The active region is embedded in a 3.6 µm thick $Al_{0.25}Ga_{0.75}As$ waveguide and 500 nm thick $Al_{0.5}Ga_{0.5}As$ cladding layers. The layer sequence is completed by a highly doped GaAs contact layer. The layer structure is shown in the inset of Fig. 1. The vertical far field angle of this super large optical cavity structure (SLOC) [12] is about 22° (FWHM). The slow axis far field angle from the back facet is smaller than 20º ($1/e^2$).

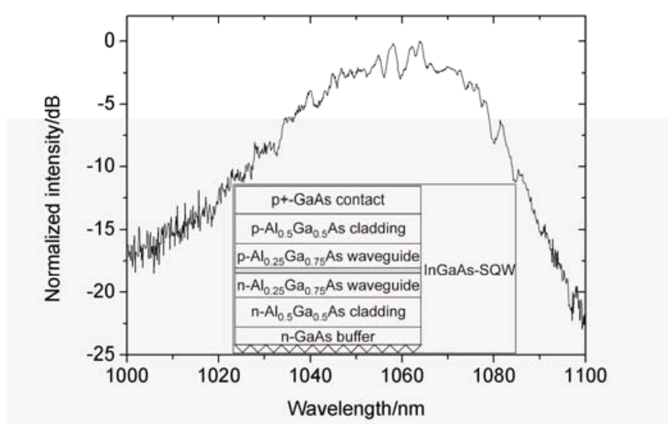

Fig. 1. Free running spectrum for the tapered amplifier at 2 A drive current and a temperature of 25ºC. The inset shows the layer structure of the amplifier.

The facets of the device were passivated [13] and after this optically coated. The rear facet of the amplifier is antireflection coated with a reflectivity below 0.1 % while the front facet is coated to a reflectivity of 2 %.

The device was mounted p-side down on a CuW submount using AuSn solder and soldered on a standard C-mount.
The emission spectrum of the free running tapered amplifier, i.e. without external grating feedback, at 2 A drive current and 25°C temperature is given in Fig. 1. The center of the emission is at 1059 nm and 99% of the emission is originated from a spectral width of 85 nm.

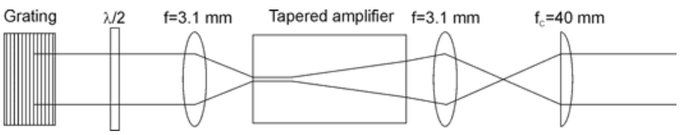

Fig. 2. Sketch of the experimental setup for the external cavity tapered diode laser. λ/2 is a half wave plate.

The tapered amplifier described above has been operated in an external cavity. A simplified sketch of the external cavity is given in Fig. 2. The beam emitted from the back facet of the tapered amplifier is collimated in both the fast and slow axes using an aspherical lens with a focal length of 3.1 mm and a numerical aperture (NA) of 0.68. The diffraction grating is ruled with 1200 grooves/mm and is blazed for 1000 nm. A half wave plate is inserted before the diffraction grating in order to rotate the polarization by 90º for maximum diffraction efficiency of the grating, which is about 85%. The grating is operated in the Littrow configuration and the grating lines are parallel to the active region of the amplifier in order to achieve better frequency discrimination. The output from the external cavity laser is collimated in the fast axis using a 3.1 mm focal length aspherical lens with a NA of 0.68. A cylindrical lens with a focal length of 40 mm is used to collimate the slow axis beam and simultaneously compensate for astigmatism.

III. Experimental Results

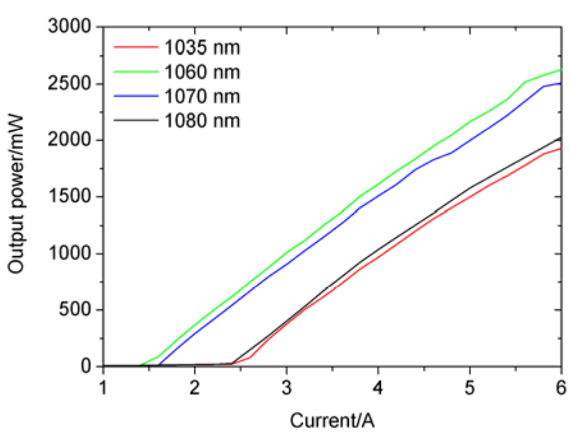

Fig. 3. Power-current characteristics for the external cavity tapered diode laser system at different wavelengths within the tuning range.

The power characteristics for the external cavity laser are shown in Fig. 3, at an operating temperature of 20ºC and at different wavelengths.

The maximum achieved output power is 2.63 W at 6 A drive current at a wavelength of 1060 nm limited by the available current from the power supply and by thermal roll over. At low currents, the slope efficiency of the laser is in the range between 0.59 W/A and 0.64 W/A depending on the wavelengths. For the wavelength close to the maximum of the free running spectrum (see Fig. 1), the threshold is about 1.5 A. This value increases to 2.5 A for the wavelengths in the wings of the spectrum. Moreover, measurements of the amplified spontaneous emission for this material show that the spectral position and width of the gain curve is independent from the excitation current. This is due to the compensation between the blue shift caused by the strong band filling and the red shift caused by the thermal heating with increasing current.

The beam quality of the external cavity tapered diode laser in the slow axis is determined by measuring the beam quality parameter M^2 at different output powers. A spherical lens with a focal length of 80 mm is used to focus the output beam. The beam diameter ($1/e^2$) is measured at various distances along the optical axis. The M^2 value is obtained by fitting the measured values to a hyperbola. The measurement is performed at different driving currents and wavelengths to evaluate the change in beam quality with output power and the result is given in Fig. 4 at wavelengths of 1035 nm, 1060 nm, 1070 nm and 1080 nm. The M^2 values did not change significantly within the tuning range.

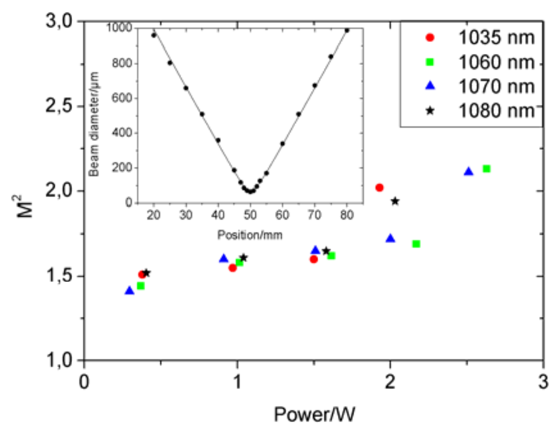

Fig. 4. Measured beam quality parameter M^2 at different driving currents for the external cavity tapered laser. The inset shows the measured beam width at an output power of 2.2 W at 1060 nm.

The M^2 of the external cavity tapered laser at wavelengths around the gain maximum stays below 1.7 up to 2.2 W output power and increases to 2.15 at maximum output power. At 2.2 W output power, approximately 80% of the power is contained in the central lobe of the beam. For this working point, the beam quality data using the $1/e^2$ method and the second moments were determined. The $M^2(1/e^2)$ was 1.7 and the $M^2(4\sigma)$ was determined to 2.1. This compares favorably to the beam quality of $M^2 < 1.4$ at 1 W output power reported by

Kelemen *et al.* [11]. The increase at maximum output power is caused by higher order modes beginning to oscillate and thus increasing the focus size. During the measurements, the position of the cylindrical lens is shifted along the optical axis to account for the change in astigmatism occurring when the current of the laser is increased. The inset of Fig. 4 shows the measured beam width for the laser at 2.2 W output power at a wavelength of 1060 nm.

Wavelength tuning of the external cavity tapered diode laser is realized by rotating the diffraction grating. In Fig. 5 the tuning characteristics of the laser are given. In the experiments, the temperature is kept constant at 20ºC and the current is 5 A.

The full tuning range of the external cavity tapered laser ranges from 1018 – 1093 nm while the FWHM tuning range is 1027 – 1086 nm with an output power of more than 1 W.

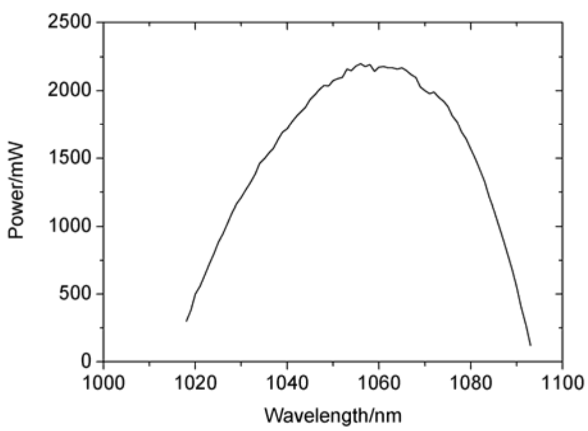

Fig. 5. Wavelength tuning characteristics for the external cavity tapered diode laser at an operating temperature of 20ºC and 5 A current.

The spectral line width of the laser is measured using an optical spectrum analyzer (Advantest Q8347) with a resolution limit of 6 pm. The spectral width (FWHM) of the laser is below the resolution limit throughout the tuning range of the laser at a current of 5 A, and the amplified spontaneous emission is suppressed by more than 30 dB limited by the dynamic range of the optical spectrum analyzer. Example spectra are given in Fig. 6 at wavelengths of 1035 nm, 1060 nm, 1070 nm and 1080 nm.

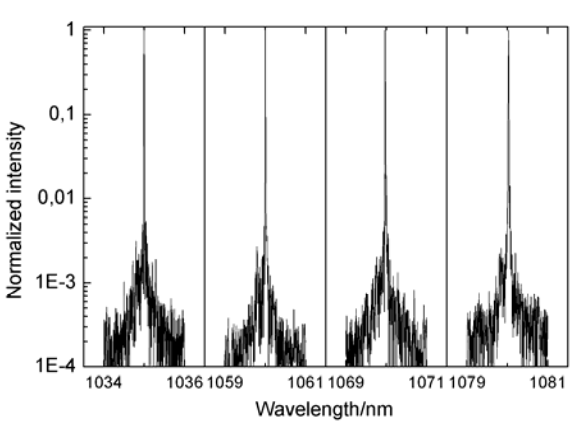

Fig. 6. Four spectra obtained for the external cavity tapered diode laser obtained at 20ºC operating temperature and 5 A driving current.

At maximum output power the spectral width increases and is in the range 30 – 100 pm with the largest line width measured at the long wavelengths of the tuning range. This could possibly be attributed to higher thermal load, less gain for the longest wavelengths or a possible slight misalignment of the external cavity.

IV. Conclusion

We have demonstrated a widely tunable external cavity tapered diode laser system around 1060 nm. More than 2.5 W of output power in a nearly diffraction limited output beam has been achieved. A wide tuning range of 75 nm has been demonstrated from 1018 nm to 1093 nm. This is to our knowledge the widest tuning range obtained from an external cavity tapered diode laser system in this wavelength range.

References

[1] O. B. Jensen, P. E. Andersen, B. Sumpf, K.-H. Hasler, G. Erbert, and P. M. Petersen, “1.5 W green light generation by single pass second harmonic generation of a single-frequency tapered diode laser,” *Opt. Express*, vol. 17, pp. 6532-6539, 2009.

[2] “Tapered Triumph,” *Nature Photon*., vol. 3, pp. 24-25, 2009.

[3] B. Sumpf, H. Wenzel, and G. Erbert, “High-power, high-brightness semiconductor tapered diode lasers for the red and near infrared spectral range,” *Proc. SPIE*, vol. 7716, pp. 77161L, 2010.

[4] J. N. Walpole, “Semiconductor amplifiers and lasers with tapered gain regions,” *Opt. Quantum Electron.*, vol. 28, pp. 623-645, 1996.

[5] M. Chi, O. B. Jensen, J. Holm, C. Pedersen, P. E. Andersen, G. Erbert, B. Sumpf, and P. M. Petersen, “Tunable high-power narrow-linewidth semiconductor laser based on an external-cavity tapered amplifier,” *Opt. Express*, vol. 13, pp. 10589-10596, 2005.

[6] G. Lucas-Leclin, D. Paboeuf, P. Georges, J. Holm, P. Andersen, B. Sumpf, and G. Erbert, “Wavelength stabilization of extended-cavity tapered lasers with volume Bragg gratings,”*Appl. Phys. B*, vol. 91, pp. 493-498, 2008.

[7] R. Ostendorf, C. Schilling, G. Kaufel, R. Moritz, J. Wagner, G. Kochem, P. Friedmann, J. Gilly, and M. T. Kelemen, “High-power frequency stabilized tapered diode amplifiers at 1064 nm,“ *Proc. SPIE*, vol. 7198, pp. 719811, 2009.

[8] S. Schwertfeger, J. Wiedmann, B. Sumpf, A. Klehr, F. Dittmar, A. Knauer, G. Erbert, and G. Tränkle, “7.4 W continuous-wave output power of master oscillator power amplifier system at 1083 nm,“ *Electron. Lett.*, vol. 42, pp. 346-347, 2006.

[9] K.-H. Hasler, B. Sumpf, P. Adamiec, F. Bugge, J. Fricke, P. Ressel, H. Wenzel, G. Erbert, and G. Tränkle, “5-W DBR tapered lasers emitting at 1060 nm with a narrow spectral linewidth and a nearly diffraction-limited beam quality,“ *IEEE Photon. Technol. Lett.* vol. 20, pp. 1648-1650, 2008.

[10] B. Sumpf, K.-H. Hasler, P. Adamiec, F. Bugge, J. Fricke, P. Ressel, H. Wenzel, G. Erbert, and G. Tränkle, “1060 nm DBR tapered lasers with 12 W output power and a nearly diffraction limited beam quality,“ *Proc. SPIE*, vol. 7230, pp. 72301E, 2009.

[11] M. T. Kelemen, J. Weber, F. Rinner, J. Rogg, M. Mikulla, and G. Weimann, “High-brightness 1040 nm tapered diode lasers,” *Proc. SPIE*, vol. 4947, pp. 252-260, 2003.

[12] A. Knauer, G. Erbert, R. Staske, B. Sumpf, H. Wenzel, and M. Weyers, “High-power 808-nm lasers with a super-large optical cavity,” *Semicond. Sci. Technol.*, vol. 20, pp. 621–624, 2005.

[13] P. Ressel, G. Erbert, U. Zeimer, K. Häusler, G. Beister, B. Sumpf, A. Klehr, and G. Tränkle, „Novel passivation process for the mirror facets of high-power semiconductor diode lasers,” *IEEE Photon. Technol. Lett.*, vol. 17, pp. 962 – 964, 2005.